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STUDY OF INDUSTRY INFORMATION  
REQUIREMENTS FOR FLIGHT CONTROL  
AND NAVIGATION SYSTEMS  
OF STOL AIRCRAFT

by John A. Gorham

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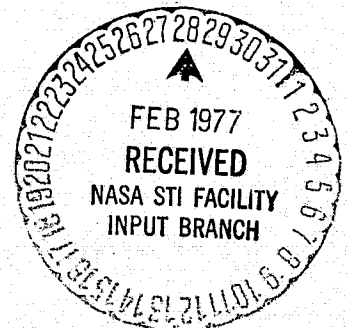
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## SUMMARY

This study was commissioned by the Guidance and Navigation Branch, NASA Ames Research Center to ascertain the data requirements associated with a guidance, navigation and control system for a future civil STOL airplane in order to improve the outputs of the STOLAND Flight Experiments Program.

During the course of the work it became apparent that it would be very difficult to establish a specific list of data, compatible with the nature of the flight experiments being conducted, which would be used directly and beneficially by the industry. The key to solving this disparity lay in an improved knowledge of the civil air transport industry design, development and operational processes.

This report, therefore, while providing the best possible answers to the specific study questions required by the contract, is mainly aimed at producing as clear a description as possible of the workings of the Guidance, Navigation and Control cross section of the civil airplane industry. This knowledge has then been utilized in recommending changes to the STOLAND Flight experiments program to improve its effectiveness.

It is hoped that the findings of this study will also be useful as a base in clarifying and refining the best format for NASA research in civil flight control and navigation systems in other flight experimental programs.

## GLOSSARY OF ABBREVIATIONS

ACs	Advisory Circulars
ADI	Attitude Director Indicator
AEEC	Airlines Electronic Engineering Committee
AIA	Aerospace Industries Association
AID	Airborne Integrated Data System
AIR	Aerospace Information Reports
ALPA	Airline Pilots Association
AMD	Aerospace Material Document
AMI	Advanced Material Information
AMS	Aerospace Material Specifications
ARINC	Aeronautical Radio, Inc.
ARP	Aerospace Recommended Practices
AS	Aerospace Standards
ATA	Air Transport Association
ATC	Air Traffic Control
ATE	Automatic Test Equipment
AWOP	All-Weather Operations Panel
BCAR	British Civil Airworthiness Requirements
BITE	Built-In Test Equipment
CAA	Civil Airworthiness Authority (British)
CRT	Cathode Ray Tube
CTOL	Conventional Take-Off and Landing
DER	Designated Engineering Representative
DME	Distance Measuring Equipment
DMIR	Designated Manufacturing Inspection Representative
DRs	Designated Representative
DOT	Department of Transportation
EADI	Electronic Attitude Director Indicator
FARs	Federal Aviation Regulations
GAMA	General Aviation Manufacturers Association
GN & C	Guidance, Navigation and Control

GPWS	Ground Position Warning System
HSI	Horizontal Situation Indicator
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
INS	Inertial Navigation System
ISO	International Standards Organization
LWM	Low Weather Minima
MLS	Microwave Landing System
MOC	Minimum Operational Characteristics
MODILS	Modular Instrument Landing System (developed experimental system for STOL by the FAA)
MPSS	Minimum Performance Standards
PVOR	Precision VHF Omnidirectional Range
RTCA	Radio Technical Commission for Aeronautics
SAE	Society of Automotive Engineers
SAS	Stability Augmentation System
SATCOM	Satellite Communication
STOL	Short Take-Off and Landing
TACAN	Tactical Air Navigation
TC	Type Certificate
TIA	Type Inspection Authorization
TRSB	Time Reference Scanning Beam
TSOs	Technical Standards Orders
VOR	VHF Omnidirectional Range
VORTAC	VOR collocated with TACAN
V/STOL	Vertical Short Take-Off and Landing

## 1.0. INTRODUCTION

The objective of the DOT/NASA STOL Operating Systems Experiments Program is to provide data to aid the design of terminal area guidance, navigation and control systems and the definition of operational procedures for powered-lift and light wing loading STOL aircraft.

There is a substantial body of both formal and informal documents which provide guidelines to the design, development, certification and operational use of flight guidance and control for conventional civil transport airplanes.

Information of a similar nature to guide the design and development of systems for STOL aircraft does not currently exist and will not until a specific need arises - a STOL airplane is funded for civil design, development, certification and operation under the appropriate FAR's and other relevant industry requirements. Suitable data outputs from the STOL Operating Systems Experiments Program could ease and expedite this task when it arises, but more importantly could provide advance information on STOL airplane flight and operational characteristics which would impact upon airborne and ground systems design.

This study has the general objective of identifying and clarifying industry information/data requirements which can be obtained from the STOL Operating Systems Experiments Program, and which could assist industry and government in the design, development and use of flight guidance and control systems and any appropriate documentation for a future civil STOL passenger carrying aircraft.

The specific questions covered in this study are:

- a) What is the civil industry documentation structure



which presently exists to guide the design and use of avionics systems for CTOL airplanes.

- b) To what extent is this data applicable to the design and use of avionic systems for STOL airplanes.
- c) What additional documentation might be required because of any unique characteristics imposed upon Flight Guidance and Control systems by STOL operation.
- d) What are the experiments (beyond those already defined for the STOL Experiments Program) needed, in order to provide the additional technical data required.
- e) How should the experimental data be analyzed and presented in order to be of most value to potential users.

Consideration of the data requirement will take account of the potential use of MLS, although the industry position on the status of MLS is still not clear and the ICAO is in the process of deliberation on the formulation of an international standard. The U.S. TRSB system is obviously a likely choice but the selection process may well impose further technical and/or operational changes to the U.S. system as currently defined. Because of this uncertainty, considerations of MLS will be limited to any obvious areas where the present specification needs clarifying or strengthening to adequately cover operation of STOL airplanes. The results of these considerations are provided in Appendix A.

This report is basically presented in four main sections:

- o The Airline Industry
- o The STOLAND Program

- o Conclusions
- o Recommendations

During the progress of formulating the material for this final report, it became clear that data which could be meaningful and useful to the industry would not necessarily be of the format originally envisaged by the Ames Flight Experiments program staff. In order to clarify this anomaly, it was felt necessary to cover quite comprehensively the "modus operandi" of those elements of the airline industry related to GN & C systems\* design and operation. The Airline Industry section, therefore, constitutes a large proportion of this report.

The STOLAND Program section is not intended to be comprehensive or complete since there are other documents which cover the program. It is provided in summary basically for the sake of completeness and also to allow the reader to better understand the recommendations as they relate to the current program. The Conclusions and Recommendations sections provide such material as can be compiled within the scope of this present study to cover the questions posed.

\*Note: GN & C - Guidance, Navigation and Control systems is generally military terminology. The civil industry, however, does not have an equivalent terminology. Systems are grouped as "avionics" or "flight control" or "navigation". AFCS represents Automatic Flight Control System or Avionic Flight Control System, depending upon the manufacturers concerned. GN & C does, in the author's view, aptly describe the genus of systems which is identified by NASA with the STOLAND program.

## 2.0. THE COMMERCIAL AIRLINE INDUSTRY

### 2.1. General

This section is intended to describe those aspects of the commercial airline industry as they relate to the design, development, production and support of flight guidance, navigation and control systems and any relevant data requirements.

The industry is broadly segregated into three groups:

- o Airlines.
- o Airframe Manufacturers.
- o Suppliers.

The airlines, of course, are the prime customer, and the airframe manufacturer, the primary supplier of the complete certificated airplane. The suppliers are the providers of equipment, responding basically to the requirements of the airframe company who in turn responds to the demands of the airline(s).

In addition to the three facets of industry, the other major element in the process of providing public air transportation is, of course, the Federal Aviation Administration who are charged by the government to ensure that the equipment used by the airlines is designed and can and will be operated in an appropriate manner to ensure safety.

So the four elements concerned with the design, production and operation of civil transport airplanes are:

- o Airlines.
- o Airframe Manufacturers.
- o Equipment Suppliers.
- o Federal Aviation Administration.

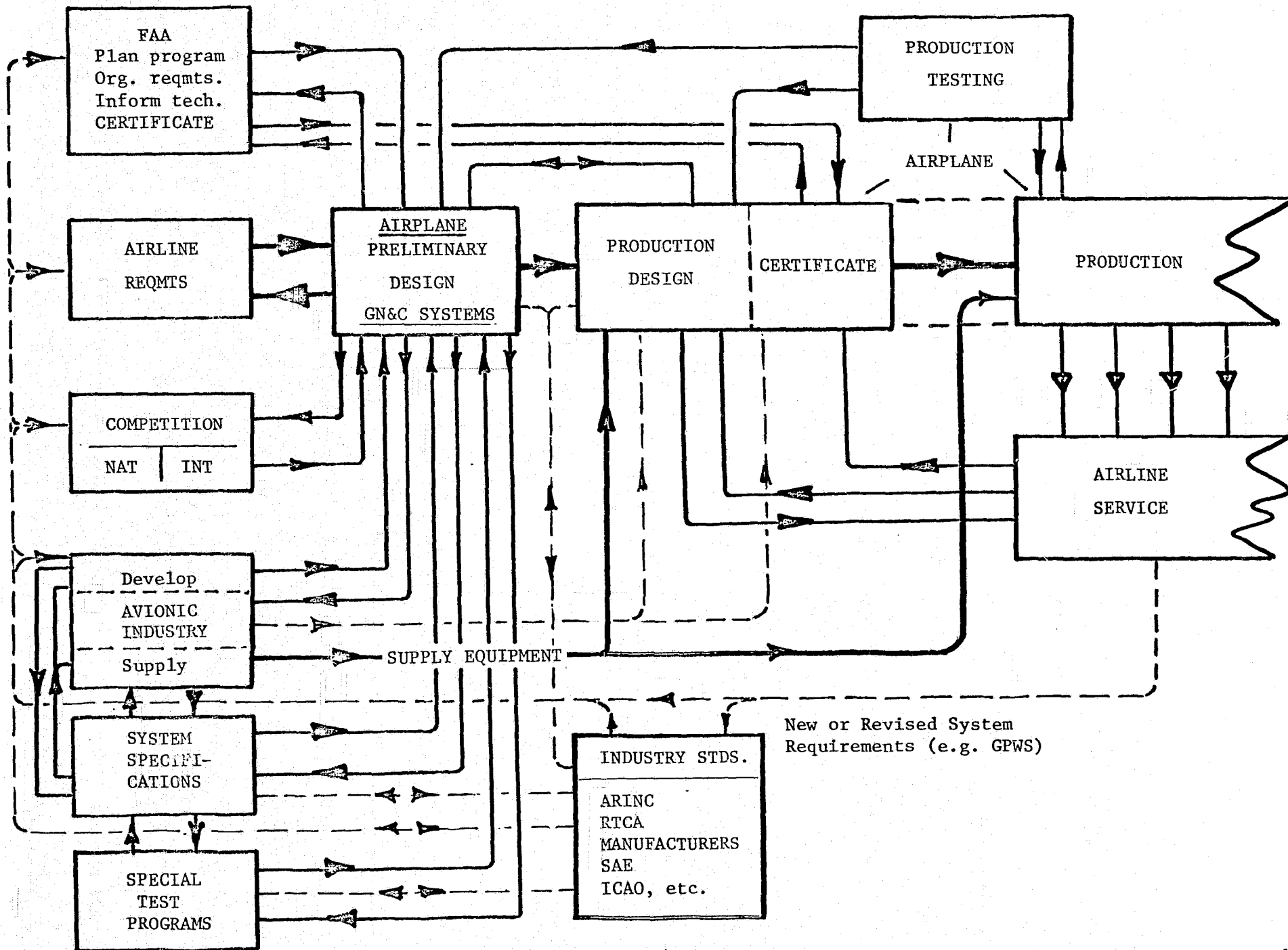


Figure 1 - CIVIL AIRPLANE DESIGN - DEVELOPMENT - CERTIFICATION - PRODUCTION DATA FLOW

Each of these groups operates individually with its own peripheral associations and services, but as an 'industry' there is obviously a very close relationship at all times. Figure 1 illustrates one facet of this relationship so far as design and test data flow are concerned. The central element in this diagram is appropriately the design, development and production of a commercial airplane, and it can be readily seen that there is a continuous interplay of information, especially during the airplane design phases. The major elements in this design and production process are described in the following sections of this report.

## 2.2. The Airlines

The U.S. airlines employ equipment which is pre-dominantly of U.S. design and manufacture. Currently, they operate a range of airplanes from Electras (circa 1955) through B-707s, 727s, 737s - DC-8s and DC-9s (circa 1960-1965), to B-747s, L-1011s and DC-10s (circa 1965-1972). The range of equipment in these airplanes is very wide, from simple PB 20 vacuum tube autopilots in the Electra to the fail-operational autoland and digital computer navigation systems of the L-1011 and DC-10. The airlines' efforts to expand their technical understanding of these new systems have been considerable, but their ability to expand their maintenance capabilities to cope with airplanes several orders more complex in little more than a decade has been truly amazing. Nevertheless, this rapid technical advance has strained financial, manpower and maintenance resources to the limit, and while always promoting greater efficiency and safety for air transportation, the airlines themselves have been obliged to restrain the incorporation of technical advances in their airplanes to a practical and manageable level. The prime objectives of the airlines must remain to operate

safely, economically and to schedule. Any new equipment advance must fulfil one or more of these objectives.

In their attempts to remain a viable transportation industry, the U. S. airlines, while competitive in day-to-day operation, employ a number of joint organizations to assist them to handle their interests with respect to the "peripheral" elements of suppliers and airframe manufacturers and the Federal Aviation Agency. In the area of GN & C systems, perhaps the best known of the airline organizations is "ARINC", Aeronautical Radio Inc. In fact, the active group concerned with avionic systems is the AEEC committee of ARINC. The other organization which becomes concerned with the control and application of technical advances into airline airplanes, is the ATA, Air Transportation Association. There are, of course, several other important organizations, such as ALPA, which represents a sector of airline pilots, but since the subject of this report is the use of technical data in the design of civil airplanes, only the activities of ARINC and ATA will be described further under this section of the report.

#### 2.2.1. "ARINC"

Although perhaps the most well known of all airline industry organizations, ARINC's functions are the least well understood. Since standardization of airline equipment is an important aspect of the use of research data in the design of airline equipment, this section is provided in some detail.

In 1929, the airlines created a specialized communications company to fulfil the many unique needs of the entire airlines industry. Aeronautical Radio Inc. is a separate entity with the U. S. scheduled airlines as its principal stock-

holders and customers, but all aircraft operators, whether stockholders or not, are provided communications service on a not-for-profit basis with service charges based on cost distribution in proportion to use. Throughout its 47 years of operation, ARINC has gained the reputation in industry and government of a successful phenomena. Throughout the 1930s and early 1940s ARINC provided a 'private line' nationwide, inter-city, point to point communications system principally through HF radio telegraph stations and a nationwide HF radio-telephone air/ground system.

Today, ARINC includes a VHF network and fulfils on-line requirements of both large and small airlines through a truly universal inter-airline automatic electronic switching message exchange service providing international air/ground communication. A multi-million annual billing is largely for services to the U.S. scheduled airlines, but includes many foreign flag airlines and the principal business aircraft operators.

The airlines industry also uses ARINC as a medium for co-ordinating communications, electronics and related matters. The Airlines Frequency Committee, the Advisory Committee on Digital Communications, the Airlines Electronics Maintenance Meeting, the Airlines Co-ordinating Committee for Telephone Services and the Airlines Communications Administrative Council with its Airlines Electronic Engineering Committee are some of the principal current co-ordinating activities. It is the Airlines Electronic Engineering Committee of Aeronautical Radio Inc. which the airlines electronic community world-wide knows as 'ARINC'. The committee normally comprises three or four ARINC staff, technical representatives of about fifteen U.S. and a few non-U.S. major airlines plus ATA, IATA, and United States Government representatives.

The Airlines Electronic Engineering Committee (AEEC) has served since 1949 to bring together the electronic engineering groups

of the airlines and other aircraft operators. These groups, together with interested electronic industry and government parties, meet several times each year, thus providing an open forum for discussion of standardization of new, current equipment and the formulation of design guidelines for future equipment, as appropriate. In coordination with the manufacturers of airborne electronic equipment and with the airframe system integrators, AEEC is mainly concerned, however, with establishing standards and specifications for new avionics (airborne electronics) equipment. These are published as ARINC Equipment Characteristics.

An ARINC Equipment Characteristic is finalized after investigation and co-ordination with the airlines who have a requirement or anticipate a requirement, with other aircraft operators, with the Military services having similar requirements, and with the equipment manufacturers. It is released as an ARINC Equipment Characteristic only when the interested airline companies are in general agreement. Such a release does not commit any airline or ARINC to purchase equipment so described, nor does it establish or indicate recognition of the existence of an operational requirement for such equipment, nor does it constitute endorsement of any manufacturer's product designed or built to meet the Characteristic. An ARINC Characteristic usually specifies "black box" details and has a twofold purpose, which is:

1. To indicate to prospective manufacturers of airline electronic equipment the considered opinion of the airline technical people, co-ordinated on an industry basis, concerning requisites of new equipment, and
2. To channel new equipment designs in a direction which can result in the maximum possible standardization of those physical and electrical characteristics which affect interchangeability



of equipment without seriously hampering engineering initiative.

The actual, detailed technical work involved in drafting an ARINC Characteristic is done mainly in AEEC Subcommittees established specifically for the purpose. The drafts thus produced are reviewed and debated by the AEEC General Session at its twice-yearly meetings. Equipment and aircraft manufacturers' representatives participate freely in these discussions at subcommittee and at committee levels. However, only the formally appointed airline members of AEEC vote to adopt a draft Characteristic at a General Session.

The primary activity of the AEEC sub-committee is to provide the airlines with "Equipment Characteristics" in sufficient detail to ensure an interchangeability of equipments from different manufacturers or in different airplanes, but not over-detailed to the point of stifling the avionic manufacturer's individual design approach. The rapid advances in equipment complexity reflects directly into the activities of the AEEC sub-committee and definition of input/output signal and power requirements are many times more difficult now than ten years ago. Nevertheless, ARINC has successfully provided "Equipment Characteristics" for the following:

<u>Sub-Committee Project</u>	<u>ARINC No.</u>		
AIDS & Flight Data Recording	563	573	591
Area Navigation	581	582	562
Automatic Chart	588		
Audible Warning System	577		
Autopilot & All-Weather Project	417		
Collision Avoidance System	587	590	
Data Link	586		

Electronic Attitude Director	
Indicator	589
Electronic Chronometer	585
FOUR-OH-FOUR Update	
(Original Racking Stds.)	404A
HF Single Sideband	533A, 559
ILS System	578
Inertial Navigation System	561
Inertial Sensor System	571
Omega	---
New Installation Concept	414 600
Passenger Entertainment & Service	
Multiplex System	574
VHF Communications (and SATCOM)	566A
VOR System	579
Weather Radar	584

The above activities are now inactive for different reasons. In some cases such as AREA NAVIGATION - 581 582 562, and INERTIAL SENSOR SYSTEM - 571, the need to produce ARINC specifications was tied to the requirements for new equipment which arose during the preliminary design phases of the L-1011 and the DC-10. Comprehensive and versatile digital computers were sufficiently developed to be employed at least in a navigation role in civil airplanes (technology available and reasonably proven) and the airlines' operational committee (under the auspices of ATA) slated a future requirement for an automated navigation capability on new aircraft. These two factors, plus a firm customer requirement and the airframe companies' willingness to meet it, caused a sub-committee to be formed immediately and the appropriate 'specs' to be processed.

It should be noted that the original "strawman" equipment characteristics were written by interested (and competitive) poten-

tial suppliers under the guidance of the airframe companies. The ARINC activity was to:

- a) Ensure as many facets as possible of airline "standardization" were considered in the time available by the interested parties.
- b) Write and produce the equipment specification in standard ARINC language.
- c) Organize the meetings and obtain the approval of the member airlines for the final "Equipment Characteristic".

Of necessity, this work was completed in record time so that final design, manufacture and certification could be accomplished to the schedule of the airplanes in which it was initially to be used.

These two projects, Area Navigation and Inertial Sensor System, are good examples of ARINC activity which produces the best industry agreement on the characteristics of size, mounting, interface wiring and "standard" signal interfaces for equipment virtually already designed for a new airplane. It should be noted in the context of this report that the primary motivation for the ARINC activities in nearly all cases of new equipment for new aircraft is the necessity to establish airplane wiring and space requirements very early in the development span of the airplane. The alternative of providing wiring, mounting arrangements and space for new equipment at any later time obviously sometimes carries unacceptable penalties.

An example of another type of ARINC specification writing activity is the well known GPWS (Ground Position Warning System) project. In this case, an unexpected requirement by the FAA caused a very fast forming of an ARINC sub-committee to establish an "equipment characteristic" mainly for the reasons of

preserving industry competitiveness. This time, however, the FAA requirement was based primarily upon the capabilities of an existing equipment. An appropriate sub-committee operated under the chairmanship of a European ARINC member - SAS, mainly because that airline had accumulated considerable experience with ground proximity warning systems.

Other activities of the AEEC sub-committee fall into the more mundane class of agreeing upon airline and industry standards for airborne avionic equipment, such as electronic chronometers, VOR and weather radar systems.

Yet another class of sub-committee activity is that of the Electronic Attitude Director Indicator - EADI. In this case, activity commenced because it appeared a requirement might arise. At present, with the advent of more complex area navigation, it now appears that effort should be directed towards an electronic HSI. Because of the lack of a firm interest and expression of need by the airlines, these activities are currently inactive.

These examples of ARINC sub-committee activities clearly illustrate why ARINC often bemoans, "Spec activity is always either too early or too late".

Sub-committee activities which are current fall into two categories:

- a) Characteristic formulation or up-grading. These include:
  - o Ground Position Warning Systems - many "nuisance" in-service warnings.
  - o Omega - definition of airborne receiver standards.
- b) Guidance papers for design or use of new equipments. These include:
  - o Automatic Test Equipment - ATE - agreement on a common software language.

- o BITE and Auto Flight Systems - intended as guidance to manufacturers on BITE design and on Digital automatic flight systems.
- o Systems Architecture and Interface - primarily covers the format and airplane system interfaces of the expanding use of digital technology.

The latter group of 'guidance' papers have a varied success. Certainly, for a group of interested parties comprising airlines, airframe companies and avionic suppliers to meet and discuss future potential problem areas is beneficial to the industry. The resulting reports, however, have not always been of the use it was hoped they would be. For instance, the attempt to formulate guidelines on autopilot design - Paper 417 - was not very successful, although it did crystallize some of the industry thinking at the time. The most consistently useful activity of the AEEC sub-committee has been, and is, the formalizing of equipment standards, and in this role ARINC is necessary and unique. The value of the guidance papers may well increase now that the design, use and maintenance of GN & C systems is becoming much more complex and interactive.

In the context of this report on the use of technical data, two points should be noted:

- a) The ARINC specification basically defines airborne electronic equipment in terms of its size, shape, pin connections, plus any essential functions or modes which would affect interchangeability.
- b) The ARINC function is to organize and ensure that a forum exists so that the basic elements

involved, airlines, airframe manufacturers and equipment suppliers, may be represented in terms of their own particular requirements or products.

Design requirements in the main, therefore, already exist prior to the ARINC specification writing process, and any further design information which becomes needed as a result of the ARINC process is provided by the industries involved in the manufacture or use of that particular item. Other than the benefits of providing the ARINC forums with status reports of the STOLAND activities, direct technical data inputs to ARINC per se would not be appropriate. Data which might be used in specific subcommittee activity would be provided by the airlines, airframe companies, or suppliers concerned.

### 2.2.2. Air Transport Association (ATA)

ATA is the trade and service organization established by the U.S. scheduled airlines to meet the needs of industry-wide planning required to provide passengers and shippers with a truly national air transport system. It began with 14 airline members as the result of a meeting in Chicago in 1936. Today, it represents 25 airlines - virtually all of the scheduled airlines in the United States and two associate member airlines based in Canada.

From its headquarters in Washington, D.C., ATA serves the public and the government on behalf of its member airlines in activities ranging from improvement of safety to planning for the airlines' role in national defense.

Top policy guidance for the Association comes from a Board of Directors elected from among the chief executive officers of ATA member airlines. The Board meets several times each year to develop priority objectives and to review progress by ATA officers and staff in carrying out these objectives. The Board also determines ATA's budget, funds which come from dues assessed member carriers on the basis of their proportionate share of revenue traffic.

The ATA committee structure is organized into four major councils:

- o Operations and Technical
  - o Government and Public Affairs
  - o Legal
  - o Economic and Finance
- and the Air Traffic Conference.

There are 22 committees within the purview of the Operations and Technical Council, as follows:

- |                              |   |
|------------------------------|---|
| o Operations                 | o Material Handling                           |
| o Flight Operations          | o Material Sales                              |
| o Air Traffic Control        | o Purchasing                                  |
| o Flight Systems Integration | o Industrial Safety & Health                  |
| o Engineering & Maintenance  | o Meteorology                                 |
| o Communications             | o Cabin Operations                            |
| o Training                   | o Medical & Sanitation                        |
| o Spec. 100/101              | o Airport Affairs                             |
| o Energy & Fuel              | o Airport Design Services                     |
| o Fastener Standards         | o Inventory Planning                          |
| o Material Management        | o Inventory Planning &<br>Supply Data Control |

Of the above committees, the first four are of direct interest to Flight Guidance and Control research activities. The basic task of the Operations committees is to foster and improve the safety and efficiency of airline operations. In conduct of the task, it has jurisdiction over many activities including:

- o Flight Operations.
- o Control, Navigation & Guidance.
- o Meteorological Support.
- o Flight Systems Integration.
- o Training, Certification & Regulation pertaining to flight crew.
- o Aviation Research & Technology pertinent to airline operations.

The Flight Operations committee responsibility is to foster and improve safety of flight operations. This encompasses surveillance of regulations, procedures, practices and other flight criteria, accidents and incidents.



The Air Traffic Control committee monitors the status and changes to the ATC system and identifies likely near term problems for appropriate action.

The Flight Systems Operations and Integration committee has the responsibility for airline matters related to flight systems. These include airborne and ground guidance, cockpit displays and controls. Category II and Category III operations are also the responsibility of this committee.

In addition to the basic committee activity, task forces are constituted as required, to advise the airlines for any specific purpose. One such task force existing at the time of this report is the Aircraft and Engine Technology Task Force which reports to the Engineering and Maintenance committee on the relevant technology and research programs which exist or are planned at this time.

So far as design data for flight guidance and control is concerned, the ATA as such, would not be a direct user, but it does have the responsibility to its member airlines to ensure that any research aimed at providing technology for the airplanes which the airlines will use is conducted in the best interests of a present and future safe, effective and economical national air transport system. Data relating to noise, psycho-acoustics and human factors could be of direct value to ATA.

### 2.2.3. International Air Transport Association (IATA)

IATA is primarily an organization supported by and representing member airlines throughout the world, and which is intended to provide the benefits of industry cooperation in technical, legal, financial and commercial aspects of air carrier operation.

During the 1960s, IATA was particularly active in the GN & C field and promoted the unique IATA Fifteenth Technical Conference on "All-Weather Operation" at Lucerne in 1963. Several hundred papers, covering all aspects of low visibility operation were given, nearly five hundred technical representatives of about thirty countries attended, and the now familiar ICAO Operational Categories I, II, IIIA, B and C, proposed by the ICAO seventh COM Division were thoroughly discussed over the ten day period of the conference. Although promoted, agreed and promulgated at this conference, the ICAO definitions of Category II and IIIA operation are virtually unchanged today, and the FAA and CAA Advisory Circulars for Category II and III operation are firmly based upon them. The potential advent of civil STOL operation, however, may now be a reason for reconsideration of the original ground rules upon which the ICAO proposals for low weather minima operation were based, since these originated predominantly from data of CTOL airplane operation. This consideration is further discussed in the Conclusions and Recommendations Section.

Today, IATA maintains an active interest in GN & C related topics, and the IATA Secretariat have voting members on most ICAO panels and committees in these areas of interest. IATA's activities include airport design, navigational aids, meteorology, communications, and other ATC related subjects.

## 2.3. The Aircraft Manufacturer

### 2.3.1. General

The role of the airframe company in the commercial airplane industry is basically to provide an airplane which will meet the customers' (the airlines) functional requirements and the Federal Aviation Administration's certification criteria.

Because of the huge financial and safety considerations in fulfilling this commitment, the airframe company must remain the design authority. For this reason, the airframe company is potentially the largest user of airplane and airplane system design data of all the elements comprising the civil airline industry. Many of the design considerations for a civil airplane are in the nature of constraints. Certainly, two overwhelming design constraints are limited time and limited money. On the other hand, today's airline management also demand a guaranteed standard of flight performance, and especially maintainability. The market place, too, demands a competitive and profitable airplane. Add to this a firm requirement to retain as many as possible of existing displays and sensors for commonality and acquisition cost reasons, and the framework within which airborne systems must be designed becomes formidably constrained.

### 2.3.2. The GN & C Systems Design Process

With any significantly complex modern airplane (a civil STOL airplane would certainly be in this category), the design process for GN & C systems is now very much an integrated process with the rest of the airplane and associated systems. Consequently, direct design data inputs are necessarily formulated at or just prior to the particular airplane design process. This was not true fifteen years ago, even with airplanes as large and complex as the B-707 and DC-8, and "off-the-shelf" systems could be and were employed (PB 20, SP 30 autopilots, etc.)

Today, each particular airplane possesses its own individually designed flight control (GN & C) systems.

The design characteristics of these systems are influenced by:

- The airplanes' allied systems (hydraulic power controls, electrical, cockpit layout).
- The particular airframe company's approach to providing the required system redundancy and switching.
- The operational and maintenance requirements of the initial airline customer(s):
- The current and envisaged industry standards, (ARINC, RTCA, SAE).
- The current certification requirements.
- The design expertise and approach of the selected supplier(s). Note: Many factors often dictate the use of only one major supplier for the total production run of a flight control system.
- The trade-off between augmented stabilization and inherent stability, structural weight handling qualities, etc.
- The cost and development risk constraints - a careful assessment of the current state-of-the-art of avionic system development.
- The competitiveness of the proposed new airplane in the national and international marketplace.

It should be noted, also, that the airplane manufacturer is responsible for the design, development, certification, guaranteed performance standards and warranties on the complete airplane, including all of the avionic and flight control subsystems (GN & C systems). Seldom in today's environment does an airline retrofit its own systems, following an initial purchase of the airplane, especially any of those related to the airplane's performance or type certification, and many of the GN & C systems of the STOLAND program would fall into these categories.

The guaranteed performance standards and, of course, the implicit assurance that the individual elements and the whole systems are flightworthy and certifiable ensure that, either a comprehensive specification of the GN & C systems is passed on to the equipment suppliers or, in some cases, a less detailed equipment specification and a shared responsibility of meeting the specified performance and certification standards.

Figure 1 may be referred to again to reiterate the complex inter-relations between many facets of the civil industry at this stage, and Figure 2, below, shows a typical schedule for a sub-sonic turbojet powered passenger airplane.

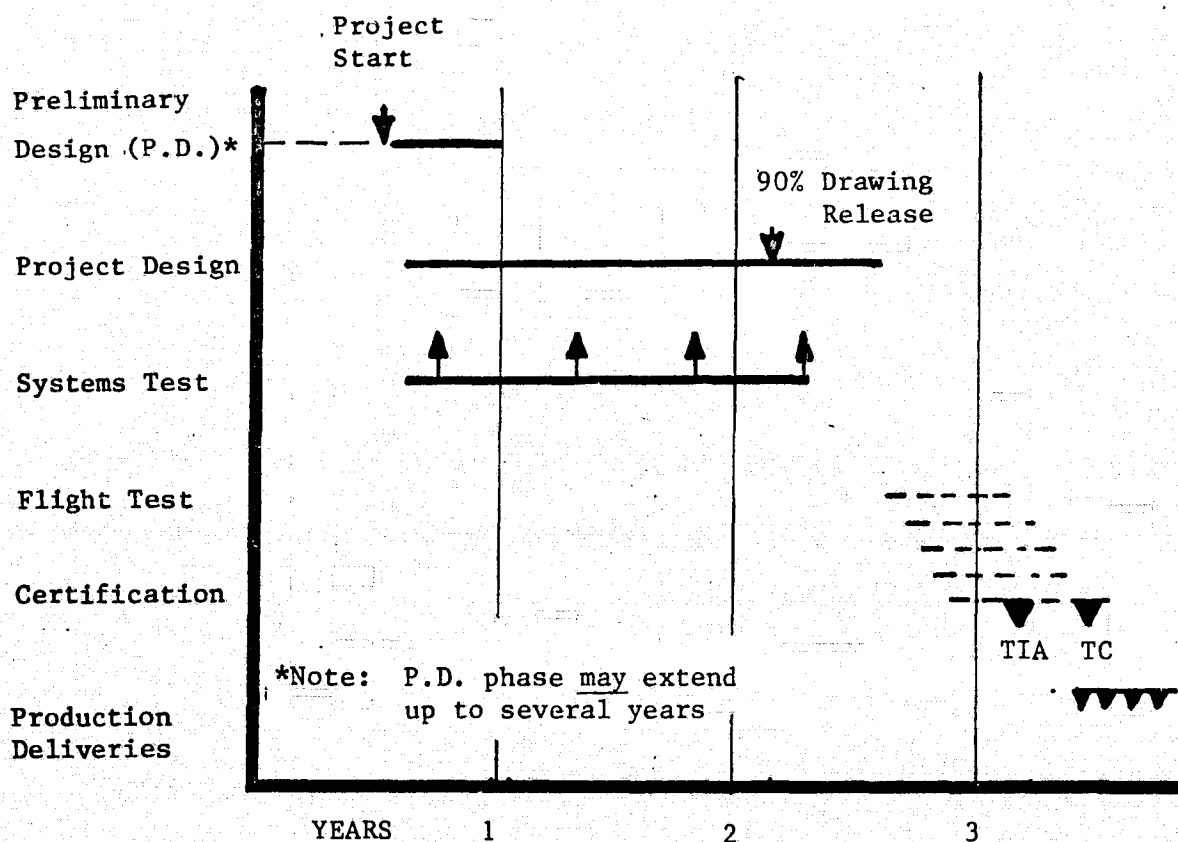


Figure 2 - Design/Production Schedule for a New Civil Airliner.

This schedule clearly illustrates one of the most significant problems in the design process of airborne systems for civil aircraft - the compressed time scale between project go-ahead and production deliveries. With the now rapid advances in technology, it is obvious that a paradox arises in the desire to use the latest technology, which may provide lower cost or improved reliability offset against the paramount need to preserve an acceptable risk level by employing adequately developed hardware.

### 2.3.3. The GN & C System Specification

Since many of the elements of the airplanes' GN & C systems are provided by the equipment suppliers, it is important that the basic requirements of the systems are established early enough to allow sufficient time for the design, development, and manufacturing process of the various suppliers concerned. In the case of the major systems, such as the automatic flight control system and the navigation system, a very comprehensive effort is required by the airplane manufacturer to define the components which will be procured, and how the interfaces with other elements and the basic airplane will be controlled.

For instance, the primary flight control system\* of a modern airplane involves, not only a sophisticated hydraulic system and surface actuators to provide the appropriate control and flight characteristics, but also a complex arrangement of monitoring and limiting which is necessary to preserve the basic safety of the airplane.

The design and functional characteristics of sensors, and there may be as many as twenty, will be dictated by economics, airlines' spares policies, multi-use with several systems and any special environmental requirements. The interfaces with several user systems will impact both the sensors and the systems concerned.

\*Primary flight control system - the electro-hydro-mechanical system for pilot manual control of the airplane.

The final outcome of these system definition efforts (often shared by the prospective equipment suppliers), is to produce a specification document for each system, sub-system or sensor to be procured. This specification must meet the cost (recurring and non-recurring) and schedule dictated by the overall airplane requirements, as well as defining the performance limits which must be met. The system, sub-system or sensor must also meet many other requirements, mostly reflecting those imposed upon the overall airplane, such as warranties, maintenance guaranties and, of course, general industry and the specific airframe manufacturers' design and production standards.

A typical specification for a sub-system in the GN & C category, such as the automatic flight control system, would impose at least the following requirements:

#### Scope

- Purpose and function of the proposed equipment.
- Definition of interfacing equipment.
- Method of development, testing and delivery.
- The certification operational standards required, especially the ICAO low visibility operational limits - Category II, or IIIA, etc., and the authorities from which certification must be obtained. It should be noted that certification by the British CAA - Civil Airworthiness Authority, (which then covers many other countries), is an important factor which influences international sales.

#### Applicable Documentation

Definition of the appropriate government/industry standards and requirements which the equipment will have to meet, including:

- FAA
  - FARs
  - ACs
  - TSOs

}

as appropriate
- CAA
  - The appropriate BCARs (British Civil Airworthiness Requirements).
- ARINC
  - General. Such as 404 - Equipment cases and racking, and 407 - Synchro systems, etc.
  - Specific. Relevant to the appropriate airborne systems involved, such as
    - 558 - Automatic Throttle system, and
    - 578 - ILS Receiver, etc.
- ATA
  - ATA 100 - Specification for manufacturer's technical data, including:
    - Parts numbering
    - Wire numbering
    - Drawing identification
    - Maintenance manuals, etc.
- RTCA
  - Environmental definition documents, such as DO-138 - Environmental Conditions and Test Procedures for Airborne Electronic/Electrical Equipment and Instruments.
- Military
  - Selected 'Mil-specs', such as
    - MIL-E-5400K - Electronic Equipment - Airborne,
    - MIL-STD-704 - Aircraft Power Supplies.
- SAE
  - Any appropriate AMSs or ASs, such as
    - AMS 2521 - Reflection reducing coating for instrument glasses.
- Airplane Control Documents
  - This includes all of the standards of design appearance, finishes, etc., which



an airplane manufacturer imposes to ensure a uniform airplane design. This documentation is extensive and, of course, differs somewhat for various airframe manufacturers.

### Design and Construction

This section would describe and impose the design and construction criteria of the subject GN & C systems. The requirements would be extensive so far as design criteria and physical characteristics are concerned, and would also reflect airline current practices for maintenance, interchangeability, etc. Elements of this section of a specification would include definition of the following criteria:

- Fault Location (trouble shooting)
- Monitoring (mainly operational)
- Tolerances
- Interchangeability
- Weight
- Size (and packaging)
- Power Requirements
- Growth Requirements
- Parameter Adjustment Requirements
- Connectors
- Electrical (grounding, bonding, etc.)
- MTBF (Mean Time Between Failure)
- MTBUR (Mean Time Between Unscheduled Removal)
- Dispatch Guarantee - The maximum permissible contribution of the GN & C system to aircraft delay.

In addition, depending upon the nature and timing of the GN & C system selection concerned, the cockpit panels, switching and warnings would be specified in varying degrees of detail.

## System Operation

While the previous sections covered the design engineering, manufacture and physical operating and interfacing qualities of the proposed new GN & C system, this section would cover the operation of the system in terms of:

- Airplane Stability and Control (when coupled to the GN & C system) - specified as damping criteria, airplane attitude limits, 'g' limits, control surface limits, etc.
- Coupled Mode Performance - normally quite rigorously specified and covering all modes including beam capture, hold, touchdown limits, airspeed limits, etc.
- Configuration - would cover all the normal and abnormal permissible operational configurations of the GN & C and interfacing systems.
- Mode Logic and Switching - again covering in detail the selection, interaction, display of all available autopilot/flight director modes.
- Warnings - would specify the physical nature and use of system warnings, such as audio, flags and lights.
- Functional Block Diagrams. The extent of detail in these will vary, depending upon the nature of the GN & C procurement in terms of timing, scope and available hardware. The airplane manufacturer will normally define the disposition of the required functions (box locations) and the control equations in varying depth. Some system elements may be defined in much more detail than others. In general, a new GN & C system is specified by quite complete functional block diagrams.

As can be seen from the above example of a GN & C specification, a new GN & C system is typically specified in comprehensive technical, physical and contractual terms, and the airplane

manufacturer's specification usually leaves flexibility only in the detailed design of the functional electronic units. Naturally, an avionic manufacturer is free to offer alternative designs, but these would seldom meet all of the requirements, and any significant modification to an existing production GN & C system might well be more expensive than reconfiguring from scratch.

It is emphasized again, however, that off-the-shelf avionic systems are often suitable for the simpler civil (especially General Aviation) airplanes, and the "custom" design process described here applies mainly to the larger, more complex airline airplanes. At this period of airplane/systems development, the custom design/development process for flight-active avionic flight control sub-systems (autopilots, stability augmentation) would generally be applicable to B-737 airplanes and up, while an off-the-shelf system for automatic flight control may well be applicable to the Gulfstream G-II and below. However, the role which the new system must fulfil in terms of safety, dispatchability and operational scope (such as Category III operation), may extend the lower limit of off-the-shelf applicability.

The situation is somewhat different for navigational guidance systems, such as navigation computers, since these systems interface much less with the airplane's active control and other relevant primary systems, and do not affect flight safety and certification of the basic airplane in the same way as can flight-active control systems. Partly for this reason, and also because a new market is opening up for automated navigation, the avionic suppliers are currently expending considerable R & D efforts in the navigation computer and display field.

The advent of more advanced and lower cost digital technology, the potential use of avionic systems in an active control (control configured) role opens up further, possibly radical, changes in the GN & C design and certification process, and the probable impact of this is covered in the Conclusions section of this report.

#### 2.4. The Equipment Supplier

So far as the manufacture and supply of civil GN & C systems is concerned, they may be divided into four groups:

- a) Automatic (Flight Director) flight control systems
- b) Navigation computers and systems
- c) Displays
- d) Sensors

There are less than half a dozen major suppliers in the world who provide and support equipment of their own design and manufacture, in all four classes, suitable for use in civil airplanes. Since the need to preserve on-time performance is always of paramount consideration to the airlines, a worldwide and competent service organization of the supplier is as essential as technical design and manufacturing ability. This element of the supply of civil GN & C systems alone significantly restricts the number of successful suppliers in this field.

Of these major suppliers of civil systems, about three of them share perhaps 75% of the market and expend sizable annual R & D funds in the GN & C area. As might be expected, it is these few suppliers who handle the development, design and manufacture of automatic flight control and other integrated systems in an exclusive joint effort with the airframe manufacturers after a new airplane program is launched. Prior to this point there is often collective and shared-cost system developments of potential new airborne systems with airframe companies, and also self-funded activities in the areas of circuit design, new display techniques, novel sensors, etc., by individual companies.

In general, it is probably true to say that in the area of Group (a) Automatic (Flight Director) flight control systems, the suppliers own R & D efforts are largely concerned with computational technology and design and manufacturing techniques. Of course, during the process of preparing for and providing proposals to airframe manufacturers, considerable study is conducted on the design application and predicted performance of the proposed new system/airplane combination.

Group (b) Navigation computers and systems, is a fast growing section of the industry because of the available technology for small, fast, inexpensive computers, and because of the traffic-handling problems of the airlines and the ATC system. Of course, the major suppliers include these new systems in their "repertoire", but, because these systems are much less integrated with the airplanes' critical-to-flight systems, some of the smaller avionic companies could become acceptable suppliers of this class of equipment provided that they can meet the service requirements of the customer. This situation may not last too long however, in the case of larger airline airplanes, since the capability of these new computers to handle many of the flight tasks, other than navigation, will lead to centralization of many flight tasks, including fuel management and flight profile control. In this event, the task of handling the larger R & D design efforts, but particularly certification and support of these systems, would probably mean that the major suppliers would again capture this business.

In the case of the smaller airplanes with less critical flight control functions, the stand-alone navigation systems must continue to increase in use and popularity.

Group (c) Displays, is another area which has been the monopoly of a very few of the major suppliers and a full range of displays including flight directors, horizontal situation in-

dicators, airspeed and vertical speed indicators, altimeters, etc., can today only be offered by two or three companies. Again, however, a major change is possible. The advent of the electronic display coupled with the greater integration of flight functions and the central computer would lead to a radical change in GN & C displays and other flight instrumentation. This is already occurring in the case of the HSI, but much research work still needs to be done in this area.

Group (d) Sensors, would include gyros, rate and position; inertial devices, accelerometers and platforms; radio receivers, VOR and ILS/MLS; Air data, individual sensors (stall warning and air pressure) and computers which provide flight display information computed from the raw data which the individual sensors provide. This group of equipment has developed relatively slowly over the past few decades. Some integration has taken place, such as the centralizing of flight attitude sensing in the vertical gyros and air data information in the air data computer. The most likely developments now would be in terms of improved reliabilities, reduced cost and weight, new techniques of sensing with less mechanical parts, and direct digital outputs to conform with the trend in flight computers and displays.

As can be seen in this very brief survey of the equipment supplier, there has been a fast advent of new technology digital computers, electronic displays, time sharing data transmission, which could greatly impact this section of the industry so far as its civil GN & C market is concerned. It is difficult to predict when or in which segment of civil aviation this will occur, and the airframe manufacturer may assume an even greater systems design responsibility than at present, especially in view of the ability of programmable centralized digital computers to perform multi-systems tasks. A large STOL airplane development with a program go-ahead in the early 1980s may well be the first application of a radical change in GN & C airborne system design..

## 2.5. Industry 'Standards' Organizations

### 2.5.1. Radio Technical Commission for Aeronautics (RTCA)

Formed in 1935, RTCA is an association of aeronautical organizations of the United States from both government and industry. Its mission is to provide leadership and guidance to industry and government by pinpointing common problems and requirements, and by recommending solutions and applications within the state-of-the-art. This includes monitoring other activities and effectively following up on approved project studies.

RTCA brings together, at the conference table, the appropriate experts from government and industry and provides a mechanism for the exchange of views and for producing agreed solutions on common problems, in all phases of aviation, involving the application of electronics and telecommunications.

The work to accomplish RTCA's mission takes place through each of its major elements: the Assembly, the Executive Committee, the Technical Advisors, the Special Committees, and the Secretariat.

The general membership of RTCA comprises over 100 government and industry organizations. Membership is open to any United States organization identified with some phase of RTCA activities. International Associate status is available to foreign organizations. Membership is not open to individuals.

The affairs of RTCA are managed by its Executive Committee. Every Assembly member is represented on the Executive Committee by a member thereof who is appointed by the organization or membership group he represents.

Technical Advisors are appointed for a period of one year by the Chairman. They act in the capacity of expert consultants to RTCA. Special Committees (SCs) are authorized by the Executive Committee. The memberships of Special Committees are drawn principally from RTCA Assembly organizations.



RTCA's scope of activities is in the field of aviation electronics and telecommunications, and in other closely allied fields. These include:

- o Determination of common operational requirements.
- o State-of-the-art developments and applications.
- o Minimum operational characteristics for airborne systems.
- o Minimum performance standards and test procedures.
- o Environmental test procedures for electronic/electrical instruments.
- o Operational and technical characteristics of systems.
- o Aeronautical frequency spectrum utilization.
- o Other problems associated with air traffic control, navigation, communications and efficient utilization of airports and airspace.

RTCA is active in any area within its scope involving common interests where competent results can be expected. This action is accomplished by:

- o Establishing RTCA work programs in those areas where action is required.
- o Monitoring activities of other organizations and, where expected results may not conform with RTCA policies or objectives, providing RTCA recommendations.

In addition, RTCA provides forums for exchange of views, follows state-of-the-art developments applicable to its field of interest, highlights areas where problems need solution, and keeps its membership informed. RTCA states technical objectives and/or operational requirements, where necessary, to reflect the common interest of its members.

RTCA recommendations find their way into the manuals and procedures of airspace users, into the regulatory proceedings of Federal agencies, mainly in the form of TSOs (Technical Standards Orders), into industry and government procurement speci-

fications, as well as being used as voluntary guidelines by manufacturers.

RTCA has completed numerous studies in recent years including:

- o Universal Air-Ground Digital Communications System Standards
- o Minimum Operational Characteristics for Airborne Systems
- o A New Guidance System for Approach and Landing (MLS)

If the activities of RTCA can be summarized, it can be said that they tend to fall into the category of a group of electronic equipment designers and users (avionic and airframe companies) formulating minimum standards for the design, test, and use of avionic communication and navigation equipment and systems. Naturally, some of the activities of RTCA fall into a broader category than this, and examples of these would be:

- SC-117 - The 'MLS' committee.
- SC-125 - Microwave Landing System Implementation.
- SC-129 - Future Civil Aviation Frequency Spectrum Requirements.
- SC-130 - Reliability Specifications for Airborne Electronics Systems.

RTCA would not use any GN & C related data directly, it would be provided as required by the industry members of the appropriate committees. The TSO itself, it must be stressed, is used primarily as a means of formalizing a minimum standard of manufacture and (sometimes) performance of avionic equipment, as a basis of FAA design approval, which then facilitates interchangeability between airplane types. Data for the TSO is derived from the MPS, the MOC and any other standards which FAA feels necessary in particular cases.

As is the case with ARINC, NASA technical data would be used by the various RTCA groups via the participating members representing the various facets of industry. Data would not normally be used directly by the RTCA staff.

### 2.5.2. Society of Automotive Engineers (SAE)

A few words on how the Society of Automotive Engineers became involved in civil aviation, may be worthwhile. The SAE was formed in 1905 to represent, primarily, the engineering aspects of the automobile industry. In 1911, some members urged the formation of an aeronautical branch, while others thought that the operation of the flimsy contraptions (the aeroplanes), should be prohibited by law. Finally, in 1916, the American Society of Aeronautic Engineers and the Society of Tractor Engineers merged with the SAE, and the National Association of Engine and Boat Manufacturers, and the National Gas Engine Association turned over their engineering and standards work to the Society. The organization of the SAE was then changed, to cover engineering and standards of automobile, tractor, aviation, marine, and stationary internal combustion engine groups.

In the context of today's organization, the sector of the SAE which is relevant to this report, is the Aerospace Council. This Council is one of five, and is responsible to the SAE Technical Board, which in turn reports to the SAE Board of Directors. The Aerospace Council handles the assignment of all aerospace technical projects, specific projects assigned to it by the Technical Board, and establishes its own procedures and policies.

The Council is composed of technical experts from the aerospace industry. The Council is responsible for obtaining and coordinating the opinions of the industry's technical experts and for developing and issuing the following documents for voluntary use by anyone who finds them suitable for their purpose:

- o Dimensional, Design, and Performance Standards.
- o Recommended Practices.

- o Information Reports.
- o Parts Standards for aircraft engines and other propulsion units, propellers, aerospace equipment, components, airframes, spacecraft, and ground support equipment.
- o Material and Process Specifications for aerospace applications.

Through the headquarter's general staff, liaison is maintained with the other elements of the aerospace industry, such as Aerospace Industries Association (AIA), Air Transport Association (ATA), General Aviation Manufacturers Association (GAMA), as well as the FAA.

Answerable to the Aerospace Council are four divisions:

#### Aerospace General Projects Division

This division covers Aerospace shock and vibration, electronic circuitry, manufacturing techniques and some power plant items.

#### Aerospace Equipment Division

This division has four groups covering:

- o Ground Equipment. Cargo standards, etc., training and simulation.
- o Aircraft. Many sections including aircraft instrument, noise measurement, lighting standards for all civil aircraft.

Of special interest to this report in this group is the now well known S-7 committee, which covers the development of flight deck and handling qualities standards.

- o Aerospace. Covers switches, relays, connectors, generators, etc.

Landing gear systems and components.

Fluid power and control technologies.

Fittings, hoses, tubings, etc.

- o Spacecraft. Environmental control systems.

#### Aerospace Propulsion Division

This division covers engine accessories, starting systems, ignition research, etc.

#### Aerospace Materials Division

This division covers, mainly, finishes and processes for metals and non-metals used in aircraft construction.

The main activities of the SAE Aerospace divisions provide the aircraft industry with the following documentation:

- o Aerospace Material Specifications (AMS)

Material and process specifications and practices.

- o Aerospace Material Document (AMD)

An interim and potential AMD.

- o Advanced Material Information (AMI)

Data on newly available materials, processes or design applications.

- o Aerospace Recommended Practices (ARP)

Dimensional, design, or performance guidance for industry.

- o Aerospace Standards (AS)

These standards cover four areas:

- (a) Design standards
- (b) Parts standards
- (c) Minimum performance (for reference in FAA TSOs)
- (d) All other standards not AMS or ARP.

- o Aerospace Information Reports (AIR)

Documentation of basic engineering data/information/guidance for use in technical areas of the aerospace industry.

- o Aerospace Technical Manuals

Manuals or handbooks in which a large amount of related information is presented in an organized form. e.g. Drawing Standards manual.

- o Publications of Other Organizations

The Aerospace Council prepares and/or reviews documents which are to be issued by outside organizations, such as the U.S. government, technical societies and organizations, etc.

- o Coordination of International Standards

The Aerospace Council has been designated as the United States National Committee for coordination of standards with the International Organization for Standardization (ISO).

One of the other important aerospace functions of the SAE is the Aeronautical Activities Committees. These committees organize national meetings and provide forums for the interchange of knowledge in many categories. Germane to this report are:

- o The Airport Facilities committee
- o The Business and Utility Aircraft committee
- o The Transport Aircraft committee
- o The V/STOL Aircraft committee

Although, like ARINC and RTCA, the Society of Automotive Engineers provides many forums for discussion of subjects,

such as the GN & C systems for a STOL airplane, in general, the primary data output of the SAE is related to detailed engineering design practices and standards of parts and materials used in the aircraft industry. The most appropriate activity of the SAE which could benefit directly from the STOLAND programme, would be the S-7 committee, which is concerned with civil aircraft cockpit design. This topic will be covered in the Recommendations and Conclusions sections of the report.

### 3.0. GOVERNMENT ORGANIZATIONS

#### 3.1. Federal Aviation Administration (FAA)

##### 3.1.1. General

This report will not cover the responsibilities and functions of the FAA in the same depth as the foregoing industry elements, and it will only cover the FAA activities and requirements appropriate to GN & C systems design and operation.

Briefly, the Federal Aviation Act of 1958 created the agency whose mission, among others, includes the continuing safety of the public in the aviation environment. Aviation safety depends on many factors, including the airworthiness of the vehicle with all its systems, equipment and instrumentation. To ensure an appropriate level of airworthiness, performance standards are prescribed by regulation. Such standards have been in existence since 1926 and have been continually developed as the state-of-the-art advanced.

The Federal Aviation Act requires the administrator to find an aircraft with all its systems, equipment, and instruments to be of proper design, material, specification, construction and performance for safe operation before he issues a type certificate for passenger carrying operation. While the FAA Headquarter's staff in Washington carries many national responsibilities for creating and upholding all of the necessary standards and regulations to ensure a safe civil aviation system, the responsibility for ensuring that a particular new design or type of airplane meets all of these standards will normally be met by the appropriate FAA region. Since Douglas, Lockheed and Boeing are all situated on the west coast, the western and north western regions conduct, by far, the biggest proportion of the basic certification work for most medium to large civil transport airplanes.



Certification of a new airplane is a process which demands a large flow of data from the airframe manufacturers to the FAA in response to the requirement to demonstrate satisfactory compliance with the appropriate FAA documentation. This documentation falls into three main categories:

- (a) The Federal Aviation Regulations (FARs)
- (b) The Advisory Circulars (ACs)
- (c) The Technical Standards Orders (TSOs)

### 3.1.2. The Federal Aviation Regulations (FARs)

These are organized into several groups, but the groups which will be considered in this report are:

- o Part 25 - Airworthiness Standards Transport Category Aircraft.
- o Part 121 - Certification and Operations Air Carriers and Commercial Operators of Large Aircraft.

While it is possible for a small light wing loading STOL airplane to comply only with Part 23 - Airworthiness Standards Normal, Utility and Aerobatic Category Airplanes, and to operate under Part 135 - Air Taxi Operators and Commercial Operators of Small Aircraft, this situation is not covered in this report for two reasons. First, there is currently an FAA/ Industry effort to overhaul Part 135, in order to upgrade the safety standards to be more nearly those of Part 121, which is covered in this report. Second, the GN & C equipment of the performance abilities being evaluated by the STOL flight experiments program is appropriate to a larger, more complex passenger carrying airplane which would probably be required to meet the standards of both, Parts 25 and 121.

Part 25 - Airworthiness Standards - generally cover the engineering design and functional performances standards to be expected from the airplane and its systems. The appropriate

sections which would have to be considered in the design and operation of STOL guidance, navigation and control systems would include but not be limited to:

- 25.171 through 181 - Airplane Stability
- 25.331 Flight Maneuver and Gust Conditions - General
  - 333 Flight Envelope
  - 335 Design Airspeeds
  - 337 Limit Maneuvering Load Factors
  - 349 Rolling Conditions
  - 351 Yawing Conditions
- 25.471 Ground Loads - General
  - 479
  - 481 } Landing Conditions
  - 483 }
  - 485 }
- 25.671 Control Systems - General
  - 672 Stability Augmentation and Automatic and Power Operated Systems.
- 25.1301 Equipment - Function and Installation
  - 1307 Miscellaneous Equipment (covers requirement for duality)
  - 1309 Equipment Systems and Installation.

This FAR is the most comprehensive and recent regulation covering the use of redundant systems for use in flight critical modes. It is basically a "catch all" regulation requiring proof of safety under all foreseeable (reasonable) failure conditions.
- 25.1329 Automatic Pilot System - The basic functional requirements for an autopilot or any aircraft system which can influence the safety of flight.
- 25.1501 Operating Limitations - General
  - 1503 through 1515 - Speed Limitations.

Part 121 - Certification and Operations - Basically, as its title implies, Part 121 covers the approval of the in-service flight operations of the airplane and the appropriate standards of airmanship and training of the aircrew who operate it.

Since the data outputs of the STOLAND program relate mainly to system design and operation, it is not appropriate to delineate specific sections of Part 121 which could be affected by STOL operation. However, many of the requirements of Part 121, such as obstacle clearance limits, landing minimums, etc., might need further consideration of their applicability to STOL aircraft.

Applicability of Part 121, as presently written, can only be determined when a new specific STOL airplane is configured and its operational role fully defined. Naturally, the definition of the STOL runway itself will play a major role in the determination of the appropriate FARs and ACs and this topic is covered in the Recommendations section of this report.

### 3.1.3. The Advisory Circulars (ACs)

Implicit within the framework of the FARs is regulation of the proper design, construction and performance of airplane systems to ensure safe operation of the civil passenger carrying airplane. When airborne systems were relatively simple, HF and VHF communication, and simple navigation and autopilot systems, interpretation of the intent of the relevant FARs was also not difficult to administer by the appropriate region responsible for the certification process.

Not only are airborne systems much more complex in today's airplanes, but they are now being used in "safety-of-flight" applications, such as automatic landing and stability augmentation. In these cases especially, the approval process be-

comes much more involved and open to interpretation, so that guidance is required to ensure that:

- a) An equal standard of approval is applied throughout the country.
- b) The best possible information is available to guide the FAA regions in their data requirements to meet particular engineering standards or operational uses of the candidate airplane.

The Advisory Circular is used to fulfil these requirements and is normally drafted with the active assistance and participation of the airline industry itself. The Advisory Circular becomes a national standard defining an "Acceptable means of compliance" for systems to be utilized for a specific function, such as Category II or Category III operation or area navigation.

It should be noted that Advisory Circulars can cover a wide spectrum of subjects, including the engineering aspects of approval, the operational use aspects of approval or just guidelines for present operation or possible future design of ground or air vehicles or facilities. Unless incorporated into a regulation by reference, the contents of an advisory circular are not binding. While the AC covers a wide variety of topics, the ones mainly appropriate to GN & C systems are prefixed with a 20 (Aircraft), 120 (Air Carrier and Commercial Operators and Helicopters), and possible 150 (Airports). Examples of current and relevant advisory circulars are as follows:

20-57A      Automatic Landing Systems

Sets forth an acceptable means of compliance, but not the only means, for the installation approval of automatic landing systems in transport category aircraft which may be used initially in Category II operations. Approval of these aircraft for use under

such conditions will permit the accumulation of data for systems which may be approved for Category IIIA in the future.

25-4

Inertial Navigation Systems (INS)

Sets forth an acceptable means for complying with rules governing the installation of inertial navigation systems in transport category aircraft.

90-45A

Approval of Area Navigation Systems for Use in the U.S. National Airspace System

Provides guidelines for implementation of two-dimensional area navigation (2D RNAV) with the U.S. National Airspace System (NAS). Provides for both VOR/DME dependent systems and self-contained systems, such as Inertial Navigation Systems (INS).

120-28A

Criteria for Approval of Category IIIA Landing Weather Minima

States an acceptable means, not the only means, for obtaining approval of Category IIIA minima and the installation approval of the associated airborne systems.

Note: This AC and 120-29 below, are the most comprehensive and important of those applicable to the installation and use of GN & C systems in Category I through IIIA weather minima.

120-29

Criteria for Approving Category I and Category II Landing Minima for FAR 121 Operators

Sets forth criteria used by FAA in approving turbojet landing minima of less than 300-3/4 of RVR 4,000 (Category I) and Category II minima for all aircraft.

Note: AC 120-29 combines AC 120-4B and 120-20 into one document.

150/5300-8 Planning and Design Criteria for Metropolitan  
STOL Ports

Provides the criteria recommended for the planning and design of STOL ports in metropolitan areas.

150/5300-8 CH 1 (4-3-75)

Transmits revised requirements for color coding of threshold and runway end lights on STOL runways.

In addition to the above ACs relating to large transport aircraft, there are also an increasing number for General Aviation aircraft which are also now employing more complex avionic systems.

Examples are:

23.1329-1 Automatic Pilot Systems Approval (Non-Transport)

Sets forth an acceptable means by which compliance with the automatic pilot installation requirements of FAR 23.1329 may be shown.

91-16 Category II Operations - General Aviation  
Airplanes

Sets forth acceptable means by which Category II operations may be approved in accordance with FAR Parts 23, 25, 61, 91, 97, and 135.

#### 3.1.4. Technical Standards Orders (TSOs)

Like ARINC, although widely discussed, the TSO is also a misunderstood function of the certification of a civil transport airplane. In the certification (airworthiness) process, the aircraft manufacturer is required to show that all of the operating systems and equipment in his aircraft are manufactured to acceptable standards and will be used within his aircraft in a safe manner. This can be done by showing the FAA that the item meets approved specifications which may be written by the aircraft manufacturer. However, if the items of the avionic systems on board a modern aircraft are interchangeable with other aircraft types, such as gyros, radios, air data computers, etc., a convenient way of obtaining approval of such items is the use of the TSO which in effect, is an equipment manufacturer and operating standard which is acceptable to the FAA.

Under the system of Technical Standards Orders currently in effect, a manufacturer of a sub-system article may be delegated the authority to certify that the particular article meets the TSO, which sets forth requirements aimed at ensuring the quality of each such article manufactured. The performance standards in TSOs have frequently been developed, in cooperation with the Agency, by an industry group which is interested in the particular article being covered, such as RTCA in the case of radio type systems (see section on RTCA), SAE and ARINC.

In effect then, certain TSOs are derived directly from applicable MPSs generated by RTCA. Manufacturers of TSO articles generally consider this concept of the MPS - TSO system advantageous because it provides them with the opportunity of disclosing publicly an official governmental approval of their articles. Another obvious advantage to the supplier is that a TSO'd item greatly facilitates its use and decreases certification costs in other aircraft types.

### 3.1.5. FAA Designated Representatives (DRs)

This section of the report on the use of data would not be complete without mention of the designated representative procedure, since it relates directly to the approval process of GN & C systems. Conducting and auditing all the certification programs, and making the individual findings prescribed by law, is a task of vast proportions, and one which grows with the steady increase in size and complexity of the aviation industry. The growth of the task has made it necessary for the Administrator to utilize the authority extended by the Federal Aviation Act, to delegate to properly qualified private persons, who could work within avionic and airplane manufacturers' facilities, any work or function respecting the examination, inspection, and testing necessary to the issuance of certificates, and the issuance of such certificates in accordance with established standards. A variety of delegations has stemmed from the authority of the Act and the ensuing delegations have become an important integral part of many certification programs. It should be noted, however, that the test results needed may be accumulated quite early in the aircraft development cycle.

Important delegations are those made to designated engineering representatives (DER) and designated manufacturing inspection representatives (DMIR). A structural engineering representative, for example, may approve structural engineering data within limits prescribed by, and under, the general supervision of the Administrator whenever he determines that the data show compliance with the applicable regulations. Other DERs approve similar data relating to powerplant installations, avionics, engines, propellers, flight analysis, flight testing, etc. DERs may be employed by manufacturers, airlines, modification centers, etc., or they may be unaffiliated private persons who act as consultants.



### 3.2. International Civil Aviation Organization (ICAO)

Since 1947, the aims and objectives of ICAO have been to develop the principles and techniques of international air navigation and to foster the planning and development of international air transport so as to:

- a) Ensure the safe and orderly growth of international civil aviation throughout the world.
- b) Encourage the arts of aircraft design and operation for peaceful purposes.
- c) Encourage the development of airways, airports, and air navigational facilities for international civil aviation.
- d) Meet the needs of the peoples of the world for safe, regular, efficient and economical air transports.
- e) Prevent economic waste caused by unreasonable competition.
- f) Ensure that the rights of contracting states are fully respected and that every contracting state has a fair opportunity to operate international airlines.
- g) Avoid discrimination between contracting states.
- h) Promote safety of flight in international air navigation.
- i) Promote, generally, the development of all aspects of international civil aeronautics.

Generally, there is a relatively high degree of uniformity between the airworthiness standards used in the various countries, particularly those which are contracting states to ICAO. There are only a very few countries which throughout the years have developed and maintained their own airworthiness standards. Other countries manufacturing aviation products have chosen to adopt their own or to use the standards of one of the other countries. Those countries which

have developed their own standards have a long tradition in manufacture or in operation of aircraft and consequently, the standards reflect a certain degree of originality. These standards, although similar to the U.S. standards in basic substance, differ in some important details and, therefore, do not represent uniformly the same level of airworthiness.

Under the current policy, ICAO's efforts in the field of airworthiness are aimed primarily at promoting international standardization through an organized exchange of technical views and the preparation of airworthiness specifications for use by individual countries. The United States participates in the ICAO airworthiness activities and considers these activities as contributing to a better mutual understanding of airworthiness problems among member countries.

A wide variety of technical, economic and legal publications is produced by the International Civil Aviation Organization. These publications, available in English, French and Spanish, include such items as Annexes to the International Convention, Procedures for Air Navigation Services, ICAO Training Manual, Regional Air Navigation Plans, Aircraft Accident Digest, Lexicon of Terms Used in Connection with International Civil Aviation, Digests of Statistics, Minutes and Documents of the Legal Committee, etc. Annex 10 to the Convention is entitled, "Aeronautical Telecommunications" and covers standardization of communication and navigation equipment and systems (Vol. I) and of utilization procedures (Vol. II).

For specific purposes, panels are formed consisting of specialists from member countries. Of special interest to the subject of GN & C systems is, of course, the All-Weather Operations Panel (AWOP), which was established by the Air Navigation Commission in early 1963. It consists of members expert in the field of all-weather operations nominated by

representative states and interested international organizations. The Panel advises the Air Navigation Commission on matters within its Terms of Reference, which are as follows:

To prepare material and recommendations relative to those aspects of all-weather operations on which international standardization is required to ensure earliest practicable introduction of an all-weather capability in the interest of improved safety and efficiency of operations.

One of the tasks of the AWOP, given to it by the Air Navigation Commission late in 1969, was the development of specifications for a new non-visual precision approach and landing guidance system for international civil aviation. In pursuing this task, the Panel first developed a statement of Operational Requirements for the new system. Subsequently, this statement of Operational Requirements was considered by the 7th Air Navigation Conference held at Montreal in April 1972 and was later approved by the ICAO Council for use as the basis for development of a new system.

That same Navigation Conference developed a three-stage programme, also approved by the Council:

- Stage 1 - The assessment of proposed systems to satisfy the Operational Requirements.
- Stage 2 - The selection of a system by ICAO.
- Stage 3 - The development of specifications for the selected system and related guidance material.

If the three-stage plan can be completed by the middle of 1977 as scheduled by the Conference, a new ICAO Standard system for non-visual precision approach and landing guidance could be introduced for use by international civil aviation by the end

of the present decade. Further, the new system is expected to be implemented initially at difficult sites where the current ICAO Standard ILS cannot provide adequate service.

We are now currently in Stage 2. Selection of the new international system is now expected to be made by the middle of 1977.

#### 4.0. The STOL Operating Experiments Program

##### 4.1. General

In 1972, the Department of Transportation (DOT) and the National Aeronautics and Space Administration (NASA) jointly agreed on a DOT/NASA STOL Operating Experiments Program Plan to solve some of the potential problems associated with STOL navigation and Air Traffic Control. Ames Research Center was given responsibility for operating a CV 340 and an Augmentor Wing Jet STOL Research aircraft. Since the original plan was approved, a light wing loading STOL aircraft has been added to the program. These facilities and their use is elaborated on in the current status section of this report.

Ames Research Center also agreed to provide the two flight avionic systems (STOLAND) and the use of a STOLAND flight simulator. The Program scope and objectives are given in the following sections and are indexed for easy reference when reading the conclusions section of this report.

Finally, it should be noted that this report on the industry use of data from the Flight Experiments program relates only to the STOLAND and STOLAND simulator aspects of the flight experiments, although the scope and objectives are given in full and also apply to work conducted by branches at Ames other than the Guidance and Navigation branch. The activities of these other branches are not covered in this report.

##### 4.2. Program Scope

The scope of the STOLAND program is outlined in the final report of the Flight Experiments committee of the joint DOT/NASA STOL Operating Experiments Steering group, issued in

July 1972. This program scope is based upon the following premises of the problems posed by operation of STOL aircraft:

- (a) STOL aircraft have the capability of changing flight path rapidly for flying complex terminal area flight paths.
- (b) They will be flying at low speed utilizing propulsive lift.
- (c) These factors will present problems in handling qualities, aircraft performance, and operational procedures required for these maneuvers.
- (d) High pilot workload for STOL aircraft in the terminal area has been identified as critical.
- (e) More effective methods of presenting information to the pilot are needed.
- (f) Data is also needed on other concepts for relieving pilot workload in terminal area operations.
- (g) STOL aircraft have unique stability problems because of the decreased effectiveness of aerodynamic parameters at low speed.
- (h) STOL aircraft have control surface inputs and powered lift which are not available to conventional aircraft.
- (i) Experiments are needed to provide data on the flight control of STOL aircraft and resultant stabilization requirements.
- (j) Data are needed on the capability of the STOL aircraft to be precisely controlled on its flight path, both in position and time.
- (k) Experiments are needed to determine the manner in which information from several navigation aids should be combined and to determine points at which information should be terminated or initiated.
- (l) Experiments should vary transition points from area navigation to approach and landing and points of

conversion of the aircraft into its STOL flight mode using powered-lift.

- (m) Experimental data are needed for a wide range of system variables to define the avionic hardware requirements for STOL aircraft and their missions, to provide design information for STOL avionics hardware between system performance, complexity and reliability.

#### 4.3. Program Objectives

The program objectives were defined in the final report of the Flight Experiments committee, and are summarized as follows:

- (a) Aircraft Performance, Ride and Handling Qualities to provide data using basic aircraft and variable stability characteristics.
- (b) Flight Control Systems to provide data on the control of STOL aircraft in low-speed and powered-lift flight and in coupled approaches.
- (c) Certification Criteria to help develop criteria for the evaluation and demonstration of airworthiness flight certification of take-off and landing performance and related flight characteristics of STOL aircraft; to evaluate operating characteristics, performance, safety margins and handling qualities; and to help determine appropriate STOL certification flight test procedures and test techniques.
- (d) Flight Path Control for Approach and Landing with the Scanning Beam Landing Guidance System to provide data to assist in determining the operational suitability of the microwave scanning beam landing guidance system for generating curved approach paths for STOL aircraft, to determine the ability of STOL aircraft to fly these flight paths, and to determine the accuracies achievable in position and time.

The experiments will assist in defining the microwave landing system requirements and in establishing the critical unique characteristics of STOL aircraft which affect these requirements.

- (e) Flight Path Control for Approach and Landing with Navigation Aids other than the Scanning Beam Landing Guidance System to provide data on navigation aids other than the Microwave Scanning Beam Landing Guidance System to assist in determining the suitability of these aids, such as VOR/DME, PVOR/DME, LORAN C, OMEGA.
- (f) Transition from Area Navigation to Approach and Landing.
- (g) Area Navigation, including Automatic Synthesis of Complex Flight Paths.
- (h) Surveillance Systems provide data to determine the adequacy of the existing ATC surveillance/communications systems to support STOL operations.
- (i) Environmental Impact to emphasize the importance of the impact of STOL aircraft on the environment to its acceptance as part of the nation's transportation system.

#### 4.4. Current STOLAND Program

The NASA Ames STOL operating Systems Program is currently operating a modified DHC-8A Buffalo Augmented Jet Flap STOL research aircraft, and has commenced initial flight development of the DHC-6 Twin Otter. The flight program of the Augmented Jet Flap (powered-lift) airplane is in the development phase at this time, and this phase is currently planned to continue through 1977. The program includes development of straight and curved flight paths, flight director and autopilot control, and automatic landing. Development of the navigation mode is basically complete, and development of the approach and landing modes and 4D speed control is in progress.

Data collection with the fully developed system is planned to commence in mid 1977 and to continue through 1979. At least



seven different configurations are planned for testing during the data collection phase including variations in thrust and pitch for speed and flight path control, including flare to touchdown.

These experiments are intended to produce data in terms of airplane performance, steep approaches, transition, etc., and airplane/system related potential problems, such as variations in powered-lift flight control. The Augmented Jet Flap STOL airplane program is also backed up by a fixed-base cab flight simulator.

The DHC-6 Twin Otter STOL program is planned to concentrate upon displays, procedures, 4D navigation, in addition to some aircraft dependent problems. The Twin Otter will be conducting straight in as well as curved de-celerating approaches and the emphasis will be upon automatic flight control (no flight director development at this stage).

The current phase of 3D profiles in the MLS and VORTAC/MLS modes commenced in May 1976, and is expected to be complete in June 1977. This phase is oriented to producing a developed airborne system for evaluating the prototype MLS installation which is expected to be available at Crows Landing in June 1977.

Other facets of STOL operation which will be investigated by the Twin Otter will be:

- o Autoland using direct lift (spoilers)
- o Various filter techniques for navigation (including minimum filtering for 3D/4D)
- o Situation display development
- o Manual flight control

Pending the installation of the prototype MLS, both the powered-lift Buffalo, and the Twin Otter aircraft will be operating on a MODILS system installed at Crows Landing.

## 5.0. CONCLUSIONS AND RECOMMENDATIONS

### 5.1. General

This study has described the processes in the design and development of a civil GN & C system. It is clear that the design definition of any proposed new system(s) is a complex process and is influenced by many other sub-systems, engineering and operational aspects of the basic airplane.

The specific design of the GN & C systems will be formulated by the industry designers concurrent with the other design decisions which must be made, such as, structural, flight controls, propulsion, flight station and other related elements of the airplane.

These factors only become resolved in detail during the preliminary design and project design phases of the new airplane program. Consequently, it may be concluded that with a new airplane of any significant complexity, it is not possible to provide detailed design data for GN & C system design in a 'cookbook' form. It would seem that a proper understanding of the manner in which modern civil GN & C systems are conceived and designed is of utmost importance in properly structuring NASA's programs so as to produce results which provide industry with the most benefits.

The following section, 5.2., will elaborate on the type of data which NASA could produce and which industry could use in its 'trade-off' preliminary design processes. A recommended set of ground rules for the STOLAND program which could improve the value of data outputs to industry is provided in section 5.3.

Section 5.4. outlines some additions/changes to the program which would further improve the usefulness to industry.

Section 5.5. and Appendix A will summarize the initial findings of this study and recommended actions concerning the TRSB Microwave Landing System.

## 5.2. Useful Data from the STOLAND Program

### 5.2.1. General

This section will discuss the nature and format of the most useful data which could be provided by the STOLAND Flight Experiments Program and will cover these under two groupings:

- a) Flight regimes
- b) Data categories

### 5.2.2. Flight Regimes

The flight regimes in which data from the STOL experiments would be most meaningful and useful to industry, are the final let-down, approaches, landings and go-arounds. Data from cruise climb, cruise, and the preliminary entry to the terminal area would be less specifically useful to a STOL designer because of the similarity of these modes to those of existing CTOL airplanes.

One unique advantage of the STOL airplane lies mainly in the flexibility with which it can carry out rapid and accurate descent profiles and turning maneuvers in a small airspace. These advantages obviously carry most weight when terminal area operations are shared with CTOL airplanes because of the improved utilization of the total airspace.

However, despite an instinctive feeling that the STOL airplane would offer benefits over the CTOL in low visibility

operation, little industry effort has been expended in defining the operational criteria which would apply to its "All-weather" performance.

Data is needed to confirm that the STOL airplane is at least as capable as its CTOL counterpart in this regard, with the minimum of added system complexity and operating costs, so that STOL feeder line operation, in particular, will be compatible under all comparable weather conditions. Following completion of the current study of the "All-weather" criteria for a STOL airplane, experiments should be conducted to confirm the criteria and determine the minimum equipment scale for acceptable performance to civil standards.

Performance in the approach and landing regime is, of course, of special interest since, for civil operation, these performance criteria especially under IFR conditions, will probably differ most from currently established airplane system design, operational and certification standards. For example, the generally accepted capture ranges, path-holding accuracy, flare height, touch-down velocities and the go-around capability, could all differ in the case of the STOL airplane, especially in the case of the powered-lift versions.

Figure 3 shows the important measurements needed to establish the performance capabilities, and the simulator and flight experiments program should gather data to establish these criteria. It should be noted, however, that this data must be statistically meaningful, and relatively large samples with a consistent system performance must be made to be useful to industry.

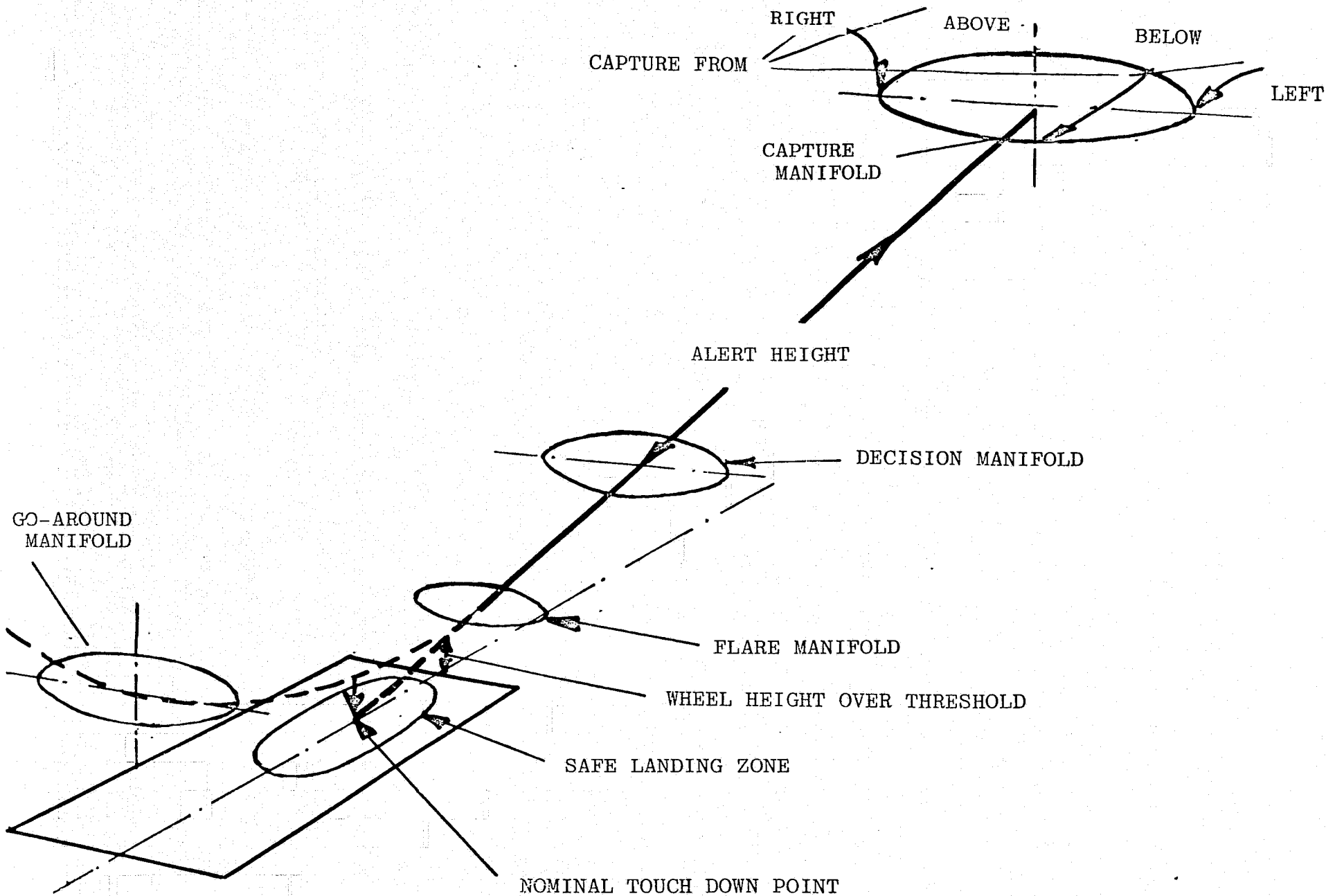


Figure 3 - APPROACH AND LANDING PERFORMANCE CRITERIA

### 5.2.3. Data Categories

Technical data which would be used by the civil industry in GN & C system design could be classified under three main groups:

- a) Performance data to assist in initial system configuration studies (Parametric variation).
- b) Data to assist in the design or selection of individual system elements.
- c) Data concerning the operational use of the system.

For group (a) above, system configuration takes into account the performance requirements, cost, weight, size, operational use, development risk, etc., for a new GN & C system, and will be specified by the airplane manufacturer, as discussed in section 2.3., The Aircraft Manufacturer.

Naturally, the maturity and availability of newly developed techniques or design elements will influence the decisions on the choice of individual sensors, computers and displays, but it is the results of the trade-off procedure which determines the configuration of the final system.

It should be noted also, as discussed earlier in this report, that rapidly advancing techniques available to the system designer may continuously change the values of the various system elements considered in the trade-off procedures.

Very early in this process of airplane design certain fundamental design decisions must be made, such as, a yaw damper or a larger rudder, direct-lift control for approach and landing or tighter tolerances on sensors and more complex computers, safety protection by limited authority or by warnings, etc.

In making these configuration decisions, all disciplines of the aircraft company become involved (as well as any potential

supplier, if relevant), and the basic elements of cost, risk, weight, performance standards, delivery schedule maintainability, are weighed against each other. During this process data is used by the individual groups to support their positions and, because of the potentially huge penalties of an incorrect decision, the data is very carefully, even cynically, scrutinized by management. This data category would be of a comparative or trend nature and this class of data could be most useful to the system configuration process as an output of the STOLAND program.

Examples of this class of data would be as follows:

- o The performance obtained by various arrangements of thrust, pitch attitude, aircraft configuration in the automatic (flight director) control of flight path in various flight regimes - transition, approach, flare, landing.  
Data may be comparative, in many cases, as well as quantitative.
- o Performance comparisons with different scales of sensors, sensor accuracies and thresholds. Much of this work can be accomplished by studies and/or simulation.
- o Influence of sub-system failures upon mission completion, e.g. Engine failure, sub-system (e.g. yaw damper) failure.

Group (b) data is that which would be more useful in the design and development of systems once their overall function has been decided and the selection of sensors, computers, and servos or servo drives is to be made. These data would help assist industry to make the appropriate decisions on sensor types, computer speeds and capacities, servo sizing, etc.

Some examples of information required in this group, and the use of the data are:

<u>Data</u>	<u>Use</u>
o Forward flight accelerations and decelerations. Influence of gyro erection errors on flight performance.	Decision on adequacy of today's standard of vertical gyros for attitude information.
o Control surface activity in all coupled mode flight conditions, including turbulence.	Needed for design of STOL airplane hydraulic system and surface servos.
o Control response characteristics. Rates, limits, resolution, thresholds.	Needed to determine details of GN & C system design.

Group (c), Operational data, is equally important to design data in the formulation of the GN & C system configuration, since it impacts pilot acceptance, basic airplane systems design, flight station design and operational approval criteria.

The GN & C system must provide information to keep the crew informed at all times of the performance progress of the system. Also, of course, the crew must be given the earliest information on any significant system failure or impending failure and, if possible, information on the best action to take in the event of this occurring. This display and warning area is especially important with a STOL airplane. Section 5.4. discusses some recommendations for a program rearrangement to reinforce the data output in this regard.

Operational data is also needed in terms of any special airplane configuration constraints or requirements when under



the control of the GN & C system, as opposed to manual flight. Examples would be:

- o Any special requirements for secondary surface or thrust settings.
- o Any special requirements for the primary surfaces trim system(s).

### 5.3. STOLAND Program Ground Rules

In order to provide the data described in section 5.2. in a convincing and most useful way, the following ground rules for the conduct of the STOLAND Flight Experiments program are recommended:

- a) The STOLAND airborne system must provide repeatable performance. Repeatable means that any anomalies can be explained by successful trouble shooting of system elements and/or by duplicating the anomaly on the flight simulator. Repeatable performance is obtained only from a consistent and reliable airborne system, and therefore, the airborne system development phase should be completed before data to be provided to industry is collected.
- b) The STOLAND airplane/system performance limits should be generally in accordance with good industry practice. That is, very accurate automatic landings could be obtained by permitting large attitude rates and angles and high 'g' levels in all axes. However, a civil airplane must conform to acceptable standards for passenger and crew.

A suggested basis for STOLAND performance is provided in Appendix B, but it must be stressed that

these maneuver limits and performance figures are based upon CTOL criteria and in some cases the STOL airplane could exceed those limits provided that passenger comfort is reasonably unchanged, i.e. bank angles could perhaps be greater because of the lower speeds involved.

- c) Ensure that the STOLAND GN & C system and interfaces with the airplane are readily and accurately modifiable in view of the recommendation to perform more parametric variation experiments.
- d) Report upon the problems as well as the successes. Industry also needs to know what not to do in terms of data on system arrangements which did not work adequately, and what fixed them.

#### 5.4. Additions/Changes to STOLAND Program

Sections 4.2. and 4.3. of this report provide a summary of the STOL Flight Experiments committees' proposed scope and objectives. From an industry viewpoint, the scope proposed for the program properly identifies the questions which must be answered during the early preliminary design phases of a new STOL airplane and system.

One area, however, could be re-examined in terms of its validity in view of the findings of this report, as follows:

-- "Experimental data are needed for a wide range of system variables to define the avionic hardware requirements for STOL aircraft and their missions, to provide design information for STOL avionics hardware, and to establish the trade-off relationships for STOL avionics hardware between system performance, complexity and reliability".

It is recommended that this element of the proposed scope is interpreted as the provision to industry of data which will enable them to define the hardware requirement and conduct the trade-off studies.

The scope definition of the human factors' problems is well stated as follows:

"Human factors' problems, such as the development of pilot display and control requirements for aircraft flight management; the development of criteria for STOL system acceptance by crew, passenger and community; and the definition of simulation requirements for STOL crew training, have been identified as critical areas which should be considered in all phases of a STOL research and development program".

The pilot switching and displays for the current Ames Powered-Lift STOL airplane have been developed to permit maximum flexibility in inputting data to, and displaying data from the airborne GN & C system. This has been necessary to suit the experimental nature of the airplane and its current program.

This built-in flexibility was obtained basically by incorporating CRT versions of current basic display arrangements - ADI, HSI, Map - a decision not unrealistic at the time the system was defined. Switching was also designed to be modular and 'flexible'. However, in the past year or so, there has been a general industry and government resurgence of interest in examining present display arrangements, data format, system switching and, above all, the influence of these items on pilot workload and efficiency. As a result of the operational flexibility and improved panel re-arrangements offered by CRT and other forms of electronic displays, there will inevitably be a period of vacillation in the best use of these new devices followed, hopefully, by improved pilots' panel arrangements for all civil transport airplanes.

It is suggested that the present powered-lift STOL airplane displays and switching are used primarily to:

- a) Fly the airplane safely
- b) Determine data to be displayed in the various flight regimes.

Specific development of individual display formats and detailed switching arrangements per se should be de-emphasized at this time. At a later stage in the flight program, an improved pilot panel arrangement should be considered as a basis for experiments and demonstration following a firming up of data needed to fly the STOL mission most effectively.

In this area of activity it appears that a somewhat piecemeal approach is presently under way by various NASA center divisions and branches. It is recommended that a positive effort be made to improve coordination between the various organizations and to commence a concerted and overall study program to establish an optimum flight station design arrangement for STOL (and CTOL, VTOL). Display and computer technology is now becoming available for a significant change (and improvement) in information presentation and, as emphasized by the Experiments Committee, the STOL airplane is an ideal candidate in terms of need and timing.

Recommended additions to the program in terms of studies of "all-weather" documentation criteria and improved glideslope and flare performance are already under way.

Finally, as this report relates, GN & C system design is a function of many elements of the airplane and its systems, and the airspace environment. To ensure the most benefit from this program, coordination between at least the following disciplines/programs should be improved and given more visibility (this is also a data output):

- o Handling qualities
- o Human factors
- o Flight simulator
- o Other CTOL and VTOL programs experimenting with GN & C systems.

Regular workshop activity (even once a year) with the appropriate sectors of FAA and the airplane designers, to compare requirements with results, would also improve the value of this program to industry.

### 5.5. The TRSB Microwave Landing System

As stated in the introduction to the main report, the relationship and status of the U.S. position on the proposed new TRSB Landing system needs to be continuously compared with the program conducted by the STOLAND Flight Experiments Program, simply because an ICAO selection has not yet been made, and further changes in the system characteristics may still occur.

Selection of the new international system is now expected to be made in the fall of 1977, but it appears that this date may slip even further. Failure to reach an international agreement during 1977 may mean a considerable delay in the introduction in the USA of a new landing system, at least one which would meet international standards. In this event, it seems probable that a STOL/VTOL landing system for civil use, providing the requisite steep angles of guidance, may need to be supplied independently of the requirements of the CTOL community. If this should occur, the STOLAND program would be especially useful in assessing the characteristics required of a STOL/VTOL only landing system.

Appendix A highlights the sections of the TRSB system specification which are especially pertinent or flexible, using current knowledge of the proposed TRSB system and of the projected STOLAND experiments. In particular, further study is needed to relate the guidance requirements of STOL automatic landing operations in very low visibilities to the current characteristics of the TRSB system. These operations impose the greatest demands upon accuracy, integrity, beam propagation and siting.

## APPENDIX A

### Preliminary Review of the United States TRSB (Time Reference Scanning Beam) Proposal dated December, 1975, With Respect to Potential STOL Requirements

#### General

The United States TRSB Proposal (Volumes 1 and 2) has been drafted with a full awareness of the need to be suitable for future civil STOL operations. However, the proposal has again been briefly reviewed in context with the proposed Ames STOLAND Flight Experiments Program and the following preliminary comments are made under the relevant section headings of the TRSB proposal. A typical airborne installation of a TRSB Category IIIA GN & C system has been studied for the Federal Aviation Administration and, although related to a CTOL airplane, these study results could also provide useful data concerning the design and operational uses of a civil Category IIIA TRSB system for STOL aircraft.<sup>1</sup>

Another document which thoroughly clarifies several of the demands of the STOL airplane on the TRSB system is an Ames/AIAA paper, presented in Los Angeles in August 1974.<sup>2</sup>

The following comments are made against the appropriate section headings of the FAA TRSB system proposal.

<sup>1</sup>A Typical Category III Airline System Configuration in a Wide-Bodied Jet Airplane, prepared for the FAA by Gorham Associates, April 1976.

<sup>2</sup>Microwave Landing System Requirements for STOL Operations by Clifford N. Burrous, Stuart C. Brown, Tsuyoshi Goka and Kun E. Park, NASA Ames Research Center, August 1974.

## Section 1.0. - Introduction and Summary

This section needs no changes since it already discusses the capabilities (general) of the system for STOL aircraft. The possibility of using the basic system in an offset mode to land on a nearby STOL strip might be considered.

## Section 2.1. - General Description

In general, this section still appears appropriate. It describes the functions obtainable from the signal. This should probably be reviewed to see if any additional specific functions might be needed for STOL operation. One question could be whether the  $\pm 40^\circ$  angle (azimuth) coverage is adequate in all cases for STOL operations, or should the  $360^\circ$  alternate coverage be provided as mentioned in 2.1.2.3.4.

The auxiliary data information in Table 2.2 should be reviewed to see if any additional data would be required for STOL operation.

Section 2.1.2.8.2.2. takes into consideration the lower approach speeds and steeper approach paths of the STOL, and states that there is compatibility with CTOL paths and speeds.

Table 2.5 should be reconsidered to confirm that the operational capabilities listed are adequate for STOL operation.

### Section 2.1.2.10 - Multipath Immunity

This section should be reviewed to see if the multipath problem is more severe at the more extreme flight path angles being used for STOL.

## Section 2.2. - Signal Format

Does not appear to require any special considerations for STOL operation.



### Section 2.3. - Ground Sub-Systems

The geometric location of the ground equipment should be reviewed from the STOL requirements, especially for operation to Category II and IIIA weather limits. Are the AZ and EL transmitters at the optimum locations for STOL? Can they be used to provide offset operation into a nearby special STOL landing strip? What are the minimum ground equipment requirements and optimum spacing for a special STOL port?

### Section 2.4. - Airborne Sub-Systems

The minimum airborne equipment requirements for STOL operation into a high density conventional CTOL airport and into a special STOL port need to be established.

### Section 3.1. - System Performance

The NASA Ames MLS system performance should be reviewed to be sure it adequately reflects the performance of the final proposed system. Any differences should be noted so that their effect on the STOLand results can be analyzed and correlated to provide meaningful results. Are differences in accuracies between the STOL test system and final proposed system of significance? Controlled runs should be made at various approach angles to compare system accuracies.

3.1.4.2. Results obtained with Twin Otter STOL at Crows Landing should be compared to results obtained under the same profiles at NAFEC to establish correlation.

### Section 3.2. - Operational Considerations

Are the assumptions made in this section for STOL aircraft valid?

3.2.2.1. What are the airborne antenna considerations and problems that may be unique to the STOL aircraft?

3.2.3.3. Be sure that the noise content of the NASA flight test facilities are compatible with the proposed TRSB system.

3.2.4. Are guidance presentation displays compatible with optimum STOLand requirements? Are newer and different displays desirable?

### 3.3. - System Integrity

This should be adequate for the STOL requirements. On-board equipment interference possibilities as mentioned should be reviewed to be sure the test aircraft is free of internal interferences that could cause non-valid results.

### 3.4. - Implementation

3.4.2.2.6.2.- Displays and Controls. This section may not be completely valid for STOL operations. A clear understanding of STOL display and control requirements for day-to-day civil airline use should be generated.

3.4.2.2.6.3. - Antennas. Much consideration should be given to STOL airborne antenna requirements to ensure adequate coverage at all times. This should be accomplished with minimum antenna amplifiers and antenna switching. Any switching or amplifying must, of a necessity, be fail-safe.

### 3.5. - System Costs

Both proposed airborne and ground equipment costs should be reviewed in arriving at the optimum minimum system for STOL only operation. What additional on-board computation is required to satisfy the STOL operational requirements?

### 3.6. - Growth Potential

These should be reviewed as to STOL adequacy. Are some of these growth features desirable initially? Should other growth features be considered?

## Volume II, Part 1 - Proposed System (cont'd)

Appendix A - Be sure NASA Ames test program is compatible with NAFEC program, so results can be maximized. If deviations are made, the reasons for these deviations and the results should be reported.

Appendix B - Section B-4 should be reviewed carefully, since it summarizes the detailed supporting data for the Twin Otter (STOL) tests at NAFEC.

Appendix C - Should be reviewed to determine if any critical areas exist at the NASA Ames test site that could adversely influence test results.

Appendix D - Should be reviewed to be sure that flight test results are given the same "Statistical Analysis Methodology", so that the NASA Ames test results are compatible with NAFEC test results.

## Part 2 - Operational Requirements

In general, this portion summarizes the system operational requirements and appears to have adequately considered STOL requirements.

Section 9.5. suggests that new types of auxiliary displays may be desirable/necessary.

Section 12.0. Azimuth Guidance should be reviewed as to adequacy for optimum STOL operation.

Section 19.0. is a handy cross reference of ICAO operational requirements (OR) with the proposed system described in Volumes I and II.

Part 3 - SARPS (Standards and Recommended Practices)

This is a good summary of terms used in Volumes I and II and should be carefully reviewed so that all active personnel in the STOLand MLS program are completely familiar with the terms and abbreviated descriptions.

Appendix A - is an addition to Part 3 above, for signal format timing and coding of MLS. This also is a must for all personnel active in the STOL GN & C test program.

Part 4 is additional summarized guidance material in the application of SARPS for MLS and should be reviewed by all concerned.

## APPENDIX B

STOLAND Performance to be met for Start of Operating ExperimentsGeneral

Adequate standards of operational performance criteria for automatic flight control systems used in civil airplanes are required for four main reasons:

- a) Safety of Flight - i.e. structural loads which can be imposed by system oscillatory modes or response to gusts or reaction of airplane following disconnect.
- b) Pilot Requirements - obviously, the main criteria here is that the automatic system must be able to fly the airplane at least as well as the human pilot, and it is expected to do considerably better. Oscillatory modes can be tolerated, but only if at acceptable frequencies and if reasonably well damped. The most important performance characteristic to be avoided is for the automatic system to operate in what the pilot would construe as an unacceptably unusual manner, e.g. the wheel or stick to move with large excursions to correct errors or large excursions in the presence of noise. A compromise of reasonable control activity with adequate accuracy is required.
- c) Airline Acceptance Criteria - In recent years, the airlines have imposed performance standards for the automatic control systems which must be demonstrated during acceptance flying. These standards are required for two reasons:
  - 1) They are a clear and unambiguous "yardstick" to measure the excellence of the airplane/system design.
  - 2) They help to ensure that there will be a minimum of "customer acceptance" problems during line service caused by erratic or oscillatory autopilot performance.

- d) Certification Criteria - In order to obtain approval to use many of the systems in a modern civil airplane, performance requirements are defined in the various advisory circulars relevant to the particular approval sought. Until recently, an autopilot or navigation system was only required to be safe and "performance" was qualitatively rather than quantitatively judged. Now, with Category II and III operation and the increasing use of "area" navigation, quite rigorous performance standards are required to be proven by the applicant. AC-20-57 and AC-90-45 are examples of Advisory circulars requiring demonstration of performance accuracy.

While some of the performance criteria required will vary with airplane type and the operational environment in which it will operate, a general standard may be defined as a guide to "good practice" for a civil passenger carrying airplane.

#### Criteria

The following criteria are designated under each axis of flight and, where they may differ, cruise and approach standards will be given separately. The criteria will be classified under one of two headings. Limits will specify maximum values for particular parameters. Performance standards will define the expected maximum deviations from the normal, all provided as two sigma values.

It will be noted that some criteria are founded upon more than one of the reasons provided above. The performance criteria are based upon current CTOL requirements or practice. Probably most of them will apply directly to STOL aircraft also (since both carry fare-paying passengers), but some may differ because of fundamental aircraft flight characteristics. For

instance, the inherently lower final approach speed of the STOL airplane may require greater bank angles (assuming that passenger sensitive maximum roll accelerations can be limited to present values, and that adequate safety margins can be preserved).

The derivation or reason for the particular figures will be defined by one or more of the following notations:

- g - good practice, based upon previous experience
- s - safety of flight
- p - pilot/passenger acceptability
- c - certification criteria (when applicable)
- a - airline requirement

#### Pitch Axis - Limits

		<u>Cruise</u>	<u>Track/Land</u>
gsp	Pitch attitude (integrator limit)	5°	18°
gsp	Pitch rate	1° - 4° per sec	5° per sec
gp	Pitch command limit		No nose down after 10 feet

#### Pitch Axis - Performance

gpa	Attitude hold	$\pm 1\frac{1}{2}^{\circ}$	$\pm 1^{\circ}$
	Beam hold		$\pm 10$ ft at 100 ft altitude
gpa	Altitude hold (level)	$\pm 20$ ft	$\pm 20$ ft
gpa	Altitude hold (turns)	$\pm 30$ ft	$\pm 30$ ft
gpc	Sink rate at touchdown	--	$\pm 1 - 3$ ft per sec (see note 4)
gp	Vertical acceleration	$\pm .03g$	--

Note 4 - Nominal sink rate depends upon gear design - figures given for an average gear stiffness.

Lateral Axis - Limits

	<u>Cruise</u>	<u>Track/Land</u>
gsp Bank angle	$\pm 30^\circ$	$\pm 10^\circ$
sp Bank angle at decrab	N/A	$\pm X^\circ$ (note 1)
sp Bank angle at land	N/A	$\pm Y^\circ$ (note 1)
gp Bank angle rate (roll rate)	$1^\circ - 5^\circ$ per sec	$4^\circ - 5^\circ$ per sec
s Drift angle	N/A	$0^\circ - 15^\circ$ (note 2)
p Lateral acceleration	.02g	.02g

Lateral Axis - Performance

ap Heading hold	$\pm \frac{1}{2}^\circ$	$\pm \frac{1}{2}^\circ$
ap Heading select	$\pm \frac{1}{2}^\circ$	$\pm \frac{1}{2}^\circ$
ap Beam hold (ILS/MLS)	N/A	$\pm 50$ ft at 100 ft altitude
gp Residual oscillations in roll not to exceed $\pm \frac{1}{2}^\circ$ bank angle.		
gpc Lateral dispersion at touchdown	N/A	$\pm 20$ ft (note 3)

Note 1 - Conditional upon geometry of airplane. Limiting conditions would be pod or tail scrape at touchdown. Typical figure might be  $4^\circ$ .

Note 2 - Drift angle at touchdown depends upon several airplane design factors such as gear strength, airplane geometry, etc. Basically, drift angle limits relate mainly to bank angles at touchdown.

Note 3 - Lateral dispersion of  $\pm 20$  ft two sigma required if STOL runway is 100 ft wide.